

Transforming Physical Crime Scene into Geospatial-based Point Cloud Data

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ABSTRACT

Terrestrial Laser Scanning (TLS) and Close-Range Photogrammetry (CRP) are advanced techniques for capturing 3D data in crime scene reconstruction, offering complementary information. Despite taking multiple scans and images from different angles to ensure a comprehensive model, limitations, such as device positioning, shadows, object distance, and laser beam angles prevent the creation of a complete crime scene model. Therefore, combining TLS and CRP data is crucial for achieving a comprehensive reconstruction. This study aims to transform a physical crime scene into a geospatial-based reconstructed model known as point clouds. The technique used was highly rich in realistic features, digitally reconstructed from TLS and CRP. The data sources were then fused via a rigid body transformation, creating a comprehensive crime scene model. The combined point cloud measurements were compared with measurements obtained from a high-precision Vernier caliper to ascertain their accuracy. The resulting Root Mean Square (RMSE) difference between the fused point cloud data and the high-precision caliper measurements was approximately $\pm 4\text{mm}$. The fusion of TLS and CRP data provides reliable and highly accurate 3D model point clouds, making it suitable for forensic applications.

Keywords-crime scene reconstruction; laser scanning; photogrammetry; data fusion; point cloud

I. INTRODUCTION

A. Crime Scene Documentation

In the past, crime scene documentation relied on detailed hand sketches to record crucial information about the

positioning of items and evidence, which played a significant role for witnesses and juries in court [1]. However, with the advancement of technology, modern methods such as 3D analysis have revolutionized crime scene data collection. These advanced techniques enable the mapping of blood splatter

patterns and facilitate comparisons of weapons, allowing for reconstructing crime scenes that were previously challenging to visualize [2]. Crime scene reconstructions are susceptible to errors and inaccuracies when relying exclusively on manual scene recordings [2-3]. The current study aims to address the limitations of individual techniques and evaluate the accuracy of a fused point cloud generated from TLS and CRP data to provide a reliable and comprehensive 3D model for the forensic analysis of crime scenes. This study emphasizes the significance of fusing TLS and CRP data to overcome the limitations of individual techniques in crime scene reconstruction. The fusion of TLS and CRP data is shown to yield reliable and highly accurate 3D model point clouds, thereby enhancing the potential of these advanced techniques for forensic applications.

B. Related Works

In [4], the precision of crime scene documentation methods was investigated, specifically measuring the distance between reference ground targets in an outdoor setting. Eight documentation techniques were evaluated relative to the established Total Station, a laser-based technology known for its efficacy in 3D documentation over long distances. The results disclosed that FARO LiDAR exhibited the highest level of conformity with the Total Station, while drones lacking Ground Control Points (GCPs) demonstrated the lowest level of agreement. This study underscored the significance of establishing a ground truth or known distance range to validate the accuracy of crime scene measurement methodologies, especially considering the introduction of new technologies and the growing demand for training and validation. In addition, this study improved the comprehension of the precision and dependability of various 3D documentation methods for crime scene reconstruction, providing valuable insights for forensic experts and law enforcement agencies. In [5], the application of 3D imaging was investigated in forensic science, analyzing several documentation methods as well as their advantages and disadvantages. This study explored non-contact techniques, such as active and passive surface scanning and the use of 3D printing in forensic applications. This research involves various duties, including preserving, evaluating, and presenting crime scenes using different 3D recording methods, and contributing to advancing crime scene investigation applications. In [6], various methods for digitizing crime scenes in 3D were thoroughly examined. The suitability of these methods was evaluated in police-related situations and the broader field of forensics. This study summarized, analyzed, and examined the effectiveness of current developments in scene documentation deploying 3D digitization and provided valuable insights into the potential benefits of these techniques for criminology.

In [7], the challenges that crime scene specialists face when presenting complex forensic evidence in court were investigated. This study highlighted the utilization of modern techniques, such as 360° imagery and laser scanning to document crime scenes. However, it underscored the limitations in presenting evidence in court due to technological inadequacies and the discrepancy between new and existing technology. Using direct experiences of crime scene examiners, this study offered useful insight into the advantages and

challenges of implementing advanced technical crime scene recording in legal contexts. In [8], a detailed approach was proposed to create 3D digital models of human crania using close-range photogrammetry and Structure-from-Motion (SfM) techniques in virtual anthropology. The particular study investigated the utilization of this technique in virtual anthropology, which could have significant implications for fields, such as medicine, archaeology, and forensic CSI. This approach allows for non-invasive and precise documentation techniques and evidence analysis.

C. Geospatial Technology Mapping

Geospatial technologies, also known as geomatics, are vital for viewing, measuring, and interpreting the Earth's surface characteristics and events. Remote sensing, GPS, GIS, and information technology are employed to map, monitor, and manage various elements of the Earth. Acquisition, storage, processing, creation, display, and sharing of geoinformation are all part of geospatial technology processes [9]. This incorporates elements of art, science, technology, and continually emerging approaches to successfully processing geoinformation. The primary focus is the management of thematic, spatial, and temporal data and the establishment of data manipulation and computing tools [10]. These cover the construction of GIS applications for spatial analysis, the design of spatial databases, and general computer programming. Fusing geospatial technologies with other analytical tools can result in more accurate data and a better knowledge of Earth's properties. One noteworthy application of geospatial technologies is the creation of digital terrain models, which have replaced previous and less exact techniques of interpreting topography. Remote sensing and GIS technologies can map and generate geomorphic maps at various scales engaging Digital Elevation Models (DEMs) of varying spatial resolutions. These technologies are especially useful in hydrological studies and help with tasks, such as rainfall estimation, forecasting, monitoring, and hydrological and water balance modeling [10]. Geospatial technologies generally improve our understanding of the terrain and provide essential tools for studying and managing water-related issues.

Furthermore, geospatial technologies have been proven effective tools for crime mapping and spatial analysis employing GIS. Crime maps aid law enforcement in identifying and locating crime problems at various levels. The GIS database includes maps with crime locations and supports other data types, like spreadsheets and multimedia information, such as pictures, videos, and audio recordings [11]. These technologies provide valuable information to study and effectively combat crime. Terrestrial Laser Scanning (TLS) and photogrammetry are advanced geospatial technologies for precise mapping and spatial analysis. TLS involves emitting laser beams to measure distances and create detailed 3D point clouds of surfaces and structures. Photogrammetry, on the other hand, relies on analyzing photographs to extract accurate measurements and generate 3D models [12]. Both methods offer complementary capabilities that enable the acquisition of high-resolution spatial data essential for geospatial mapping, urban planning, environmental monitoring, and infrastructure development.

D. Terrestrial Laser Scanning (TLS)

Terrestrial Laser Scanning (TLS) is used in land surveying to capture detailed information about the terrain and ground characteristics [13]. It functions as a terrestrial version of Light Detection and Ranging (LiDAR), producing point clouds that encompass a horizontal coverage of 180° and a vertical coverage of 270° [14]. This scanning process enables the collection of precise data about the landscape and its features. Compared to point-based data collection techniques employed by GNSS and total stations, TLS can capture and record 3D geospatial information [15].

E. Close-Range Photogrammetry (CRP)

Close-Range Photogrammetry (CRP) refers to the technique of capturing measurements when the camera-to-subject distance is within 300 meters. Stereo pair photos are essential for precise measurements in CRP. Although terrestrial photogrammetry is commonly deployed for landscape mapping, CRP can map or measure almost any surface or object. The popularity of photogrammetry has reached an advanced optical-based data acquisition system [16]. This technology has grown due to the availability of digital cameras, fast data processing capabilities, and adaptable precision in measurements. With advances in consumer-level digital cameras and the accessibility of 3D modeling software, CRP has emerged as a viable alternative to 3D laser scanning. Although it is not as powerful or precise as laser scanners, it has applications in various fields, including automotive, archaeology, civil construction, medicine, and forensics [17]. The accuracy of photogrammetry models depends on factors such as the number and quality of captured photos. If the camera captures low-quality images, the resulting model will also be of lower quality.

F. Point Cloud

Point clouds are digital representations of real-world objects or structures, capturing detailed information, including RGB colors, dimensional measurements, sizes, and volumes [15, 18]. They are generated using specialized lenses with LiDAR systems commonly found in TLSs [19]. Point clouds possess specific data characteristics that make them sparse, irregular, and continuous. They represent 3D structures and retain per-point features, such as color, intensity, and normal vectors [20]. These features remain consistent regardless of scale, rigid transformation, or order [21]. Due to these unique traits, conventional deep learning models struggle to extract meaningful features from point cloud data. Therefore, existing models need modifications or new approaches to handle point cloud data effectively.

G. Point Cloud Fusion

According to [22], it has been established that no single sensor can capture all the information about an object. Therefore, data fusion becomes crucial to provide users with a consistent and reliable data representation. Data fusion involves merging information from multiple sources and disciplines to create a high-quality dataset. The fusion of diverse data sources, as suggested in [23], enhances the quality of information and accelerates data processing activities. The main objective of this study is to combine two different sources

of point cloud data, namely TLS and CRP, into a unified hybrid point cloud. The process of creating this hybrid point cloud involves cloud registration, which ensures alignment between the data from both sources. By employing registration methods to merge TLS and CRP point cloud data, a comprehensive and detailed representation of the object or structure can be achieved, providing valuable insights for various applications.

H. Point Cloud Fusion Method

In the industry, three widely used approaches for cloud registration are Iterative Closest Points (ICP) [24], Feature Extraction and Matching (FEM) [25], and Match Box Bounding Center (MBBC) [26]. ICP is an iterative method that refines the alignment between two-point clouds until the best fit is achieved. FEM focuses on extracting and matching key features from the clouds to ensure accurate alignment. MBBC uses bounding boxes to identify overlapping areas and align point clouds accordingly, offering an alternative approach to accomplish registration.

I. Crime Scene

A crime scene is the specific location where unlawful activities occur, leaving behind evidence and traces of the criminal actions within a particular time and space. It can include both indoor and outdoor areas where the discovery of crime-related evidence takes place. The collection of physical evidence directly from the crime scene is a crucial aspect undertaken by law enforcement or private investigators. The analysis of a crime scene serves as the initial and pivotal step in solving a crime, significantly influencing the success of investigations. In traditional crime scene analysis, valuable information and insight is derived from the evidence and findings present at the scene. Given the uniqueness of each crime scene, skilled crime scene investigators employ a logical and systematic approach to effectively analyze even the most complex scenarios [27]. Scientific investigation of a crime scene involves several crucial steps, including meticulous documentation, such as measurements and photographs, thorough collection and proper packaging of physical evidence, and comprehensive reconstruction of the crime scene to provide a coherent understanding of the events.

II. METHODOLOGY

A. Crime Scene Setup

Before beginning the data collection phase, the study area was chosen. The Geospatial Forensic Satellite Lab at the UTM Faculty of Built Environment and Surveying was selected as the study location. In this regard, a mannequin and various crime scene evidence, such as a knife, were meticulously placed in a room with input from an experienced industry expert who has specialized in forensic photogrammetry for more than six years. Figure 1 displays the scene simulation. To create a seamless 3D model, the data acquisition process must be meticulously planned. This involves ensuring adequate image overlap, with a minimum of 60% overlap across all image collections. The angles for capturing images with the CRP and the TLS placement were carefully determined after setting up and outlining the crime scene to meet the specified criteria. The positioning of the TLS can be observed in Figure

2. Square checkerboard scanning targets are used to aid in the registration process as part of this research.



Fig. 1. Scene simulation.

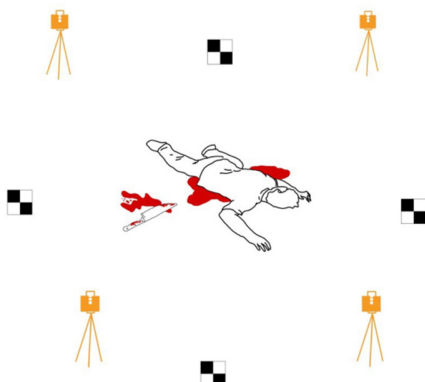


Fig. 2. Objects setup.

B. Data Acquisition

The simulated crime scene was set up indoors at the UTM-PDRM Geospatial Forensic Satellite Lab, Universiti Teknologi Malaysia (UTM) in Johor Bahru, Malaysia, under the supervision of an industry expert. Once the crime scene is established in a limited area, data collection commences by deploying a TLS and a Digital Single-Lens Reflex (DSLR) camera. The DSLR camera captures photographs of the crime scene from various angles, ensuring its comprehensive representation. Figure 3 presents a detailed list of the equipment used in the study.




Equipment	Leica BLK360	Nikon Z50	Vernier Caliper
			

Fig. 3. Equipment used.

The data acquisition stage commences in the subsequent phase, utilizing the CRP method. This involves capturing a series of images from the crime scene utilizing a DSLR camera. A laser scan is also performed employing the TLS at the crime scene, as depicted in Figure 4.



Fig. 4. Data acquisition using TLS.

The camera station consisted of eight stations, and thirty-four images were captured during the operation. The camera configuration was set to be convergent, optimizing the image quality and accuracy. In addition, four scan stations were put into service for TLS, allowing for comprehensive data collection and analysis. After the completion of data acquisition through TLS and CRP, each object present at the crime scene is measured using a Vernier Caliper (VC), as illustrated in Figure 5, to determine its length, following the conventional method. The comparison of these additional measurements is crucial to evaluate the precision of the collected data.



Fig. 5. Data acquisition using VC.

Different equipment was implemented during this phase of the study. CRP entailed taking images of small evidence pieces with a Nikon Z50 hand-held camera. The Leica BLK360 was chosen for laser scanning. Targets or markers were affixed to surfaces to improve accuracy, allowing for the alignment of multiple images during the acquisition process.

C. Data Processing

Following data collection, the collected data were transferred for further processing. The initial step in creating the 3D model, utilizing the point cloud, involved applying the Structure from Motion (SfM) technique within the Agisoft software. This software fuses important functions, such as Align Photo, Build Dense Cloud, Build Mesh, Build Texture, and Export Model. Figure 6 demonstrates the process of utilizing CRP photographs in Agisoft. During the scanning procedure, significant noise was generated by reflective surfaces, necessitating removal before utilizing the data for analysis. Noise reduction is necessary to effectively use the data. The presence of noise posed challenges in creating a

comprehensive 3D point cloud of the crime scene. To proceed, the data from the TLS device had to be imported into the CloudCompare software. Subsequently, the point cloud originating from the TLS underwent a cleaning process known as segmentation, wherein the focus was on isolating the precise regions of interest. Figure 7 exhibits the output of the TLS data before segmentation with the unwanted point cloud.

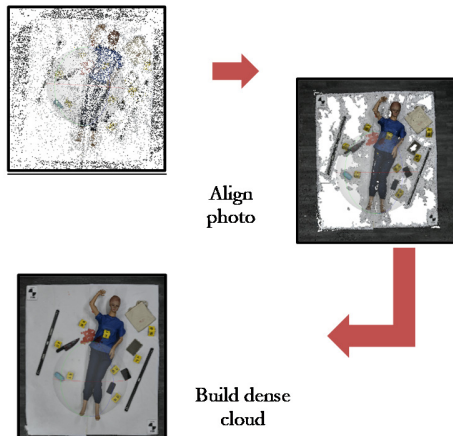


Fig. 6. The processing workflow for CRP images.

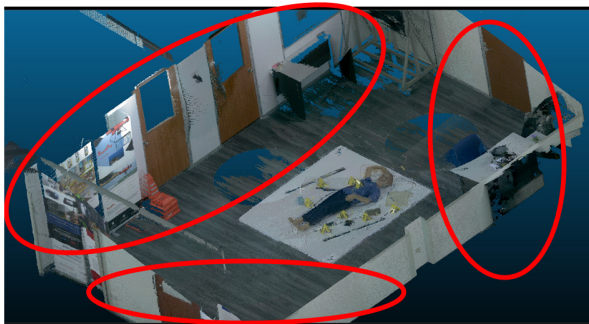


Fig. 7. The unwanted point clouds.

After completing the data cleaning process, the point cloud emerges more refined and ready for further utilization and analysis. To create a comprehensive 3D model of the simulated crime scene, merging the point clouds obtained from CRP and TLS is crucial. The fusion process is carried out deploying CloudCompare software. The workflow begins with the import of the point clouds derived from CRP and TLS into the software. Then, the align (point pair picking) method is followed to register and align the two-point cloud entities, effectively completing the fusion procedure as shown in Figure 8.

The point pair-picking approach involves manually selecting at least three common points between the entities. The more common points chosen, the greater the similarity between the models is. Point pair picking is a robust technique for registering two sets of point clouds, as it relies on human judgment to identify similar features. For the fusion process, a total of 8 common points between the datasets were selected. Table I presents the accuracy of the alignment between these two data.

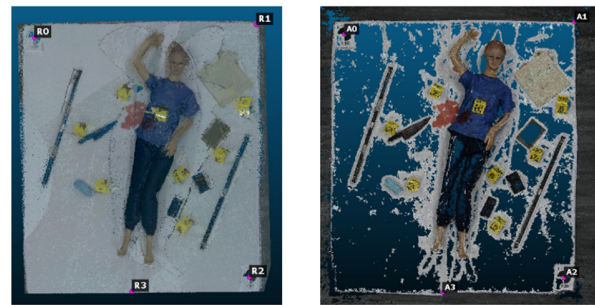


Fig. 8. Point-pair picking method.

TABLE I. RMSE OF FUSION OF THE SELECTED POINTS

Final RMS		0.00657383	
Transformation matrix			
0.996	0.028	0.000	-12.453
-0.017	0.605	-0.792	-0.250
-0.023	0.791	0.605	-13.716
0.000	0.000	0.000	1.000
Scale (already integrated in the above matrix)		0.996583	

The RMSE result was obtained through a procedure that aimed to find the optimal transformation to align the points in one cloud with the points in another. The resulting RMSE value represented the average distance between the corresponding points after alignment. A lower RMSE indicated a more favorable alignment outcome, whereas a higher RMSE suggested a less satisfactory alignment. This information proved to be valuable for evaluating alignment quality and making any necessary adjustments.

III. RESULT AND ANALYSIS

A 3D model from images and point clouds was generated using the Agisoft software. This process yielded a 3D model point cloud and a 3D point cloud. The resulting point cloud, consisting of approximately 6,260,806 points, provided complete coverage of the simulated crime scene. The data acquired from the TLS were processed using the Cyclone software for registration, while the CloudCompare software was employed for data cleaning. The processed data was saved in the "las" format and consisted of 2,449,791 points obtained from TLS. The findings indicate that the simulated crime scene exhibited fewer details than the data obtained through CRP, as displayed in Figure 9. This discrepancy can be attributed to the influence of paint colors on the intensity readings of LiDAR technology [28].



Fig. 9. The output obtained from CRP and TLS.

By fusing the mesh and texture derived from the point clouds of each sensor, a surface is generated for the fused point cloud model. This fusion process improves the visual aesthetics of the model, enhancing its realism and making it more visually appealing for visualization purposes, as observed in Figure 10.



Fig. 10. Fused point cloud from TLS and CRP.

The fusion of point cloud data obtained from CRP and TLS presents a dynamic and robust 3D data acquisition method. CRP captures intricate textures and fine features by extracting detailed point cloud data from multiple images. This aspect makes it ideal for small to medium-sized objects. In contrast, TLS rapidly captures millions of points in a scene, making it well-suited for large-scale environments and outdoor scenes. By combining these two techniques, their strengths complement each other, resulting in a more comprehensive and precise representation of the scanned object or environment. The CRP-generated single-point cloud excels at providing high-resolution surface information. On the contrary, the TLS-derived single-point cloud offers accurate measurements for large-scale scenes. By leveraging their combined strengths, this hybrid approach significantly improves data quality and opens up new possibilities for various applications, including heritage preservation, architecture, and virtual reality. Professionals in these fields can greatly benefit from the specific approach, transforming the way 3D data are captured and utilized. The synergy between CRP and TLS enables the creation of more detailed and accurate 3D representations across various industries and practical uses. The accuracy of the devices deployed was evaluated by measuring various objects, as detected in Table II.

TABLE II. RESULTS OF EVIDENCE MEASUREMENT

No.	Items	Measurement (mm)		
		TLS	CRP	VC
1	Phone	87	81	81
2	Wallet	110	99	100
3	Knife 1	125	121	120
4	Knife 2	45	42	40
5	Knife 3	81	82	70
6	Glasses case	57	55	60
7	Notebook	163	143	140
8	Card 1	89	90	90
9	Card 2	81	89	90
10	Card 3	85	88	90

The accuracy evaluation involved extracting measurements from CRP and TLS data using the CloudCompare software. Additionally, manual measurements were obtained to compare the conventional method with the model reconstructed implementing CRP and TLS. These measurements, including the combined data from both sensors, were compared with the benchmark measurements acquired with a VC. The quantitative assessment focused on measuring the lengths of evidence at the crime scene. RMSE was utilized as a metric to analyze and assess the accuracy of these measurements.

$$RMSE = \sqrt{\frac{\sum_{i=1}^N (y_i - \hat{y}_i)^2}{N}} \tag{1}$$

where y_i is the actual value, \hat{y}_i is the observed value, and N is the number of observations. Data were tabulated in 10 sample sizes according to the following calculation:

$$\Delta l_1 = VC - TLS \tag{2}$$

$$\Delta l_1 = VC - CRP \tag{3}$$

$$\Delta l_1 = VC - i \tag{4}$$

where:

$$i = VC - \text{Combined point cloud}$$

$$\Delta l_1 = VC - TLS$$

$$\Delta l_2 = VC - CRP$$

$$\Delta l_3 = VC - i.$$

Table III displays the quantitative analysis results, where the measurement error was calculated employing the RMSE. This measurement error represents the difference between the measurements obtained adopting the CRP and TLS techniques and those acquired using the VC. A lower RMSE value indicates a more reliable model. In this case, the RMSE values were 7 mm for TLS and VC, 5 mm for CRP and VC, and 4 mm for the combined data and VC. The findings indicate that the combined data model exhibited the lowest RMSE, which makes it the most accurate among the three models. Figure 11 depicts a visual chart showcasing 10 samples from the datasets, illustrating the RMSE of the combination of CRP and TLS compared to the VC.

TABLE III. DIFFERENCE OF MEASUREMENT

No.	Items	Difference of measurement (mm)		
		Δl_1	Δl_2	Δl_3
1	Phone	5	-1	-2
2	Wallet	-2	-2	-2
3	Knife 1	0	-4	-2
4	Knife 2	6	3	-4
5	Knife 3	-2	-1	-3
6	Glasses case	-4	-6	-3
7	Notebook	17	-3	7
8	Card 1	-2	-2	1
9	Card 2	-10	-10	0
10	Card 3	-6	-6	-6
RMSE		7	5	4

According to the quantitative analysis, there was only a minor difference between the combined data and the on-site

measurements. The measurements on the notebook and card 3 showed a larger and less accurate difference than the rest. This is mainly because of the point cloud quality generated from this evidence. In simpler terms, the data obtained on notebook and card 3 did not produce results as clear and reliable as the other evidence. The calculated RMSE value of around 4mm indicates a minor change. This demonstrates that the combined data are suitable for forensic applications and can achieve high accuracy. According to [29], the combination of TLS and Airborne Laser Scanning (ALS) can lead to an accuracy of less than 4mm.

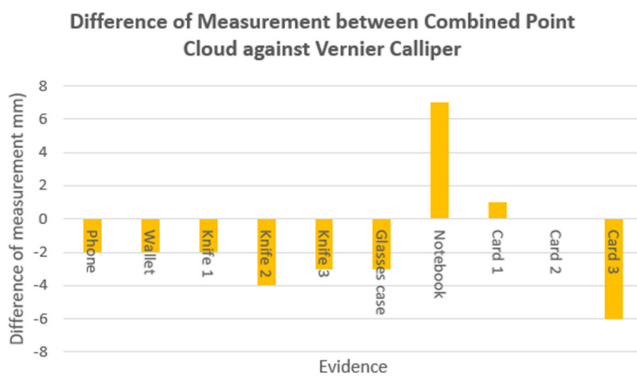


Fig. 11. Difference of measurement between fused point cloud and VC.

IV. CONCLUSION

This study investigated how TLS and CRP improve crime scene analysis. Fused data from TLS and CRP were tested for minor evidence capture. The current study demonstrated a 3D geospatial-based documentation method of a crime scene consisting of forensic findings or physical materials useful for crime scene investigation. A Vernier caliper was used to obtain measurements and compare them with those obtained from a Leica BLK360 TLS and a Nikon Z50 CRP. The CRP method produced more point cloud data than other approaches, and its visual output was better than that of TLS. Several factors explain the difference in visual quality between the two procedures. The TLS's restricted scanning capabilities may have degraded data quality due to its cramped location. The CRP output was much better visually. CRP deploys texture and color images for better reconstructions. However, TLS lacked integrated picture capture, and any built-in camera delivered poorer-quality photographs than a DSLR. To conclude, the fused data created an accurate 3D model point cloud for forensics. Combining TLS and CRP improved the visual quality of forensic point clouds.

Advanced computer tools and methods are recommended to automate data fusion and alignment, saving human labor and enhancing data fusion efficiency. Intelligent computer systems and algorithms that learn from data could also minimize shadows, improve device orientation, and optimize laser data collection angles. TLS and CRP could be combined with unmanned aerial aircraft or mobile scanning devices to improve data collection and crime scene modeling.

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